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(54) VARIABLE BUOYANCY ARRANGEMENT

(71) We, THE WIREMOLD COMPANY, a Corporation organised under the Laws of the State of Connecticut, United States of America, of Hartford, Connecticut 06110, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to equipment carried by a person during his underwater activities to control the aggregate buoyancy of himself and his equipment to enable him to effect a desired buoyancy with respect to the depth of his activities or facilitate his ascent or descent in the water.

For underwater activities such as military demolition and hazard fabrication, salvage and treasure recovery, scuba explorations and the like, a diver is equipped with an air source for breathing, and typically loaded with sufficient weight to characterise the system comprising the diver and his equipment as having a neutral, or substantially neutral buoyancy. This permits the diver to move about, and to select his vertical water depth under his own physical power while expending energy only to overcome inertia and develop motion, and not to maintain a desired depth once it has been attained.

However, this weight selection process is only approximate at best. Further, when the buoyancy forces acting on the diver change, e.g. by decreasing when the volume of the diver and his equipment decreases under the influence of increased water pressure at greater depths, normally referred to as "suit squeeze", or by increasing when the weight of the diver and his equipment decreases as his air is consumed (typically a change of several pounds), the diver is forced to reduce or add to his weighting (or to change the volume of his equipment) to maintain a neutral buoyancy. This is often accomplished by picking up rocks from the water bottom and carrying the rocks about, clearly a cumbersome and insecure procedure.

Further, a diver must often swim significant distances at water level to go between a starting point, such as an anchored craft, and the desired diving area. Thus he must expend considerable energy swimming on the surface in a buoyancy condition much better suited to underwater swimming.

It is thus an object of the present invention to provide improved underwater manoeuvring apparatus.

More specifically, an object of the present invention is the provision of apparatus for selectively varying the buoyancy of the diver and his apparatus without employing cumbersome weighing elements.

According to the invention there is provided in combination in a variable buoyancy arrangement adapted for underwater activity, a tank of substantially fixed volume for selectively storing water, means for maintaining the interior of said tank within a predetermined pressure range above the underwater ambient pressure, means for selectively introducing water into said tank, and means for selectively discharging water from said tank.

In one embodiment the apparatus includes a tank of fixed volume having as one input thereto a valve configuration for supplying air characterised by a pressure within a fixed range above that of the ambient environment. A push button actuated valve is employed to selectively actuate a water pump, with the pump being responsive to each depression of the valve button to force a fixed quantity of water into the tank chamber. An output conduit is connected to the tank for selectively passing water outward therefrom, under control of a stop cock, with the water being discharged under the action of the above-ambient internal tank pressure when the stop cock is open.

The user of the above apparatus may decrease his buoyancy as changing conditions from time to time dictate by depressing the valve actuating button, thereby causing the pump to force additional water into the tank chamber. Since the chamber is of fixed volume, the additional water supplies an in-

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cremental downward force while causing no additional water displacement thus not increasing the upward buoyancy force acting on the diver. Correspondingly, to increase the system buoyancy by a desired amount, the stop cock is opened and water is forced out of the pressurised chamber, thus reducing the system weight, but not its volume. Swimming along the water surface is facilitated since the chamber can be purged of water and thus act as a flotation aid.

The invention will now be described in greater detail, by way of example, with reference to the accompanying drawings, in which:

Figure 1 depicts in schematic form a first variable underwater buoyancy arrangement embodying the principles of the present invention, and

Figure 2 illustrates a second variable underwater buoyancy arrangement.

Referring to Figure 1, a variable buoyancy arrangement there shown includes a tank 12 which is adapted to exhibit a constant volume when the inside thereof is pressurised. The tank 12 may thus be fabricated either of a rigid material such as metal or a hard synthetic plastic, or of an air-inflatable material such as canvas which will not stretch beyond a fully expanded volume. Any desired shape will suffice for the tank 12, although a form contoured for comfortable mounting on the back of the user about the user's air supply cylinder is most convenient.

To supply air under higher than ambient underwater environmental pressure, an air source 10 is provided. In the preferred form illustrated, this is the main air cylinder carried for underwater breathing purposes which commonly contains air under a pressure of several hundred pounds per square inch (p.s.i.). Before reaching the tank 12, the high pressure air undergoes several pressure reductions as follows. The source 10 is connected to a pressure regulating valve 15 of conventional form which reduces the air pressure, e.g., to about 100 p.s.i. above the ambient underwater pressure for delivery to two branch conduits, one 16 leading to the user's breathing apparatus and the other 17 leading to an additional pressure regulating valve 20. Since the pressure of the air leaving the first pressure valve 15 is still too high for use in the buoyancy control devices, the second pressure reduction valve 20 further reduces the pressure, e.g. to about 15 p.s.i. above ambient pressure. From the exit port of the second valve 20 two branch tubes 21 and 22 conduct the air, on one hand to a final pressure reduction valve 28 (in the tube 21) to the tank 12, the reduction being to about 5 p.s.i. above ambient pressure or 10 p.s.i. below the supply which is regulated at 15 p.s.i. above ambient pressure. Alternatively, the valve 28 may be of the regulating type to develop the requisite 5 p.s.i. above ambient pressure. Thus, the branch tube 21 supplies air under pressure to the buoyancy tank 12 at the desired pressure.

The other branch tube 22 from the valve 20 is provided to supply air pressure to a system for controlling and adjusting the amount of water in the tank 12 to decrease its buoyancy. This is done selectively by providing in the branch tube 22 a conventional two-position button-actuated valve 30 to one exit port of which is connected a tube 33 leading to an air pressure actuated pump 50. The valve 30 normally is biased as shown in the drawing to connect the tube 33 to a vent tube 35 exposed to the underwater environment. The valve has a button 31 which when pressed by the user moves a valve plunger 34 to cause interconnection of the tubes 22 and 33. When the button 31 is released the return of the valve plunger 34 to normal position reconnects the tubes 33 and 35 while blocking the tube 22. Suitable embodiments for the valves 15, 20, 28 and 30 discussed hereinabove, as well as additional valve elements considered below, are well known to those skilled in the art, and these devices need not be described further.

The pump 50 includes a housing 51 having an "air" port at one end and a "water" port at its opposite end. The housing 51 has a piston or a flexible diaphragm 52 therein which is biased upward, i.e. toward the "air" end of the housing by a compression spring 54. Water may selectively flow into the pump housing 51 through its "water" end, i.e. beneath the diaphragm 52 through the entrance port 56 of a one-way check valve 58 whose exit port is connected by a conduit 60 to the pump's "water" end. When the button 31 of the pump-control valve is depressed, compressed air at 15 p.s.i. above the underwater ambient pressure flows through the elements 22—10—33 to the pump 50, thereby forcing the diaphragm 52 to the downward position 52′ as shown by dotted lines in the drawing. This forces out of the pump a fixed quantity of water defined by the volume between the diaphragm in its up and down positions 52 and 52′. To deliver this volume of water to tank 12, a branch 61 from the conduit 60 connects to the inlet of a one-way check valve 64 whose outlet is connected by a conduit 65 to tank 12. The unidirectional nature of the check valves 58 and 64 prevents discharge of water from the pump except to the tank, and prevents flow of water from the tank back into the pump.

When the button 31 is released, the tube 22 is blocked by the valve 30, and the area above the diaphragm 52 is vented to the ambient environment through the tubes 33 and 35. Accordingly, with the pump actuating air pressure thus removed, the compressed spring 54 pushes the diaphragm 52 to its

quiescent raised position. This motion of the diaphragm 52 creates a reduced pressure in the lower portion of the pump 50 which draws water therein through the check valve 58 and the conduit 60. The pump 50 is thus charged and in a primed condition to discharge a like quantum of water into the tank 12 when the valve 30 is again actuated by the button 31.

To remove water selectively from the tank 12, a conduit 72 having a normally closed stop cock 74 affixed thereto is connected to the tank 12. When the stop cock is opened, the internal pressure in the tank 12, which is always at least 5 p.s.i. above the external ambient pressure, forces water out of the tank through the elements 72—74.

Finally, a pressure relief valve 70 is connected to the tank 12 and adapted to open when the internal pressure of the tank 12 exceeds a predetermined pressure level above ambient, which pressure level is intermediate the pressures developed by the valves 20 and 28, e.g. 10 p.s.i. above ambient pressure. This fixes the maximum internal pressure of the tank 12 at 10 p.s.i. above ambient pressure, thus constraining the pressure within the tank 12 to always be in the range between 5—10 p.s.i. above ambient pressure. This in turn, ensures that the 15 p.s.i. (above ambient pressure) which actuates the pump 50 will always be sufficient to overcome the internal tank pressure and drive water into the tank 12 each time the button 31 is depressed, and further ensures that the internal pressure of the tank 12 is sufficiently greater than the ambient pressure to force water out of the tank 12 into the local environment when the stop cock 74 is opened.

The button 31 and the stop cock 74 are advantageously mounted in a convenient location readily accessible for user control. If desired, a two-position valve 30 embodying a remote control actuating mechanism in plate of the valve button 31 may be employed, with the remote control mechanism being contained in a place convenient for the user and the remainder of the valve 30 being located as desired.

With the above arrangement in mind, an illustrative sequence of operation will now be described. A diver just beginning his journey starts with the tank 12 substantially free of water and with an internal pressure of 5 p.s.i. above ambient pressure; as produced by the high pressure air supply 10 acting through the regulating valves 15 and 20 and the reducing valve 28. The user swims on the water surface to the diving area with the empty tank 12 serving as a flotation aid and not an encumbering weight which has to be transported.

At the diving location, the diver repeatedly actuates the button 31 to change his status positive to neutral or slightly negative buoyancy. With each depression of the button 31 the pump 50 responds in the above-described manner to air pressure from the 15 p.s.i. above ambient regulator valve 20 acting through the tubes 22 and 33 and the valve 30 by forcing a fixed quantity of water through the path 60—64—65 into the tank 12. Since the tank 12 is of a fixed volume it displaces a fixed volume of water when submerged. Thus when any water is introduced into the tank by the pump 50, it directly subtracts from the buoyancy forces acting on the user and his submerged equipment.

At neutral or slightly negative buoyancy, the diver is free to move about under water as he desires without expending energy to maintain his underwater depth. As the buoyancy of the diver and his equipment decrease, e.g. because of the increased water pressure as he moves to greater depths, he may compensate by releasing some of the water pumped in at the surface to begin his dive, and as his buoyancy increases because the user expends his air supply or moves to shallower waters with less pressure and less "suit squeeze", the user simply pushes the button 31 to inject more water in the tank 12.

Since the valve system 15—20—28 develops an output air pressure measured on an ambient, environmental-responsive basis, all pressure relationships are maintained, including the relatively small, 10 p.s.i. maximum gradient between the interior of the tank 12 and the water pressure on the outside thereof. Accordingly, the tank is not crushed at great water depths, even when fabricated of materials which are not naturally form-retaining or do not possess sufficient mechanical strength to retain the form of the tank at ambient underwater pressures.

When the diver wishes to increase his buoyancy, either as an assistance in rising or to correct for an overweighted condition, he opens the stop cock 74 for a desired interval. The cock 74 opens and the air pressure within the tank 12, being in the range of 5—10 p.s.i. above the external water pressure, forces water out of the tank through the conduits 72 and the cock 74. Thus the downward weight force acting against the upward buoyant force is decreased.

During an ascent, the ambient pressure will reduce until it becomes 10 p.s.i. less than the pressure within the tank. Then the relief valve 70 will open. Air will exhaust from the tank 12 through the valve 70 to maintain the 10 p.s.i. tank-water pressure differential.

Thus, the variable buoyancy arrangement depicted in Figure 1 and discussed in detail above is readily operable under control of the user to generate any desired buoyancy condition for the user and his equipment vis.-a-vis. the surrounding underwater environment.

A second embodiment of the present invention, shown in Figure 2, includes a tank 12 of constant volume when the inside thereof is pressurised, and may be essentially identical to the like numbered tank 12 of Figure 1. As before the air source 10, which may comprise the main air cylinder carried for underwater breathing purposes, supplies air under high pressure to the pressure regulating valve 15 which reduces the air pressure to a relatively low level, e.g. to about 100 p.s.i. above the ambient underwater pressure. Air from the reducing valve 15 is delivered to four branch conduits 16, 180, 181 and 182. The air conduit 16 leads to the user's breathing apparatus; the second conduit 180 conveys air to a stop valve 106 via a valve 116 for selectively expelling water from the tank 12; the third conduit 181 leads to a slide valve 123 which, when actuated, operates a pump 150 for inserting a fixed charge of water into the tank 12; and the fourth conduit 182 conveys pressurised air to valve apparatus 80—86—98 for maintaining the interior of the tank 12 within a fixed pressure range (e.g. 3—5 p.s.i.) above the ambient underwater pressure.

To insert water into the tank chamber 12, thereby decreasing diver buoyancy, the pump 150 is adapted to insert a fixed quantity of water into the tank 12 each time it is operated by the valve 123. The pump 150 is advantageously located within the tank, although it may be externally mounted and coupled to the tank by suitable conduits. The pump 150 includes a cylinder 152 having a drive piston 154 which slides therein. The drive piston 154 includes first and second (e.g., upper and lower) surfaces thereon adapted to drive a follower member when a pressure gradient is impressed thereacross, as more fully discussed below. A connecting rod 156 connects the drive piston 154 with a follower piston 158 having a plurality of ports 162 therein. The ports 162 are sealed by a flapper (check) valve member 160 during the active pumping stroke. A pump housing 151 includes a plurality of ports 153 therein through which water passes into the tank 12 during an active pump stroke. The ports 153 are sealed by a flapper (check) valve member 166 which seals these ports under urging of the internal tank pressure at all other times.

A passageway 174 connects the pump to the underwater medium. Two conduits 132 and 134 are connected to the pump cylinder 152 on either side of the piston 154, and connect the piston cylinder to the slide valve 123 which is selectively operated by a push button 121 biased by a spring 122 to a rest position.

The valve 123 includes a slide member 136, having three apertures 138, 140 and 142 thereon, for selectively connecting one of the conduits 132 or 134 to the relatively high air pressure output of the regulator valve 15 via the conduit 181, and for venting the other conduit 132 or 134 to the underwater medium through one of two exhaust orifices 126 or 128. In particlar, with the valve 123 in its normal inactive state as shown, the slide aperture 140 connects the conduit 132 to the pressurised conduit 181, and the aperture 138 connects the conduit 134 to the exhaust port 128. Correspondingly, when the valve 123 is operated by depressing the button 121, the aperture 142 vents the conduit 132 via the port 126, and the valve 15 supplies air pressure to the conduit 134.

With the valve 123 in its rest position, the pressure above the piston 154 (that generated by the regulating valve 15) exceeds the ambient pressure beneath the piston, and the piston 154 resides at the bottom of the cylinder 152 against a stop 155. Water flows through the passageway 174 and around the follower piston (indicated by arrows 170) into the pump housing 151. The water is prevented from flowing through the pump exit ports 153 by the flapper 166 which is maintained against the ports 153 by the internal tank pressure.

To insert the water residing in the pump housing 151 into the tank 12, the operating button 121 of valve 123 is depressed. As discussed above, this couples a relatively high pressure to the bottom of the drive piston 154 via the conduit 134, while venting the cylinder 152 above the piston 154. Accordingly, the piston 154, along with the connecting rod 156 and the follower piston 158, are forced upward toward a stop 155′.

During this active pumping stroke, the follower piston 158 and its covering flapper member 160 create a pressure which forces water through the ports 153 and into a tank chamber, while forcing the flapper member 166 away from the exit side of the ports 153, as to the position 166′ shown in dotted lines. The volume of water inserted in the tank is essentially given by the cross-sectional area of the pump housing 151 multiplied by the length of the active piston stroke, i.e. the height of the cylinder between the stops 155 and 155′. At the end of the active stroke, the pump no longer exerts a pressure on the flapper 166 which is returned to a position sealing the ports 153 by the internal tank pressure.

When the operating button 121 is released, and thereby reset to its normal position by the spring 122, the pressure gradient between the conduits 132 and 134 is reversed, and an excess of pressure above the driving piston 154 resets it to its normal, or rest position against the stop 155. The connecting rod 156 forces the follower piston 158 along with its flexible flapper member 160 to their downward normal position.

Water is drawn into the pump housing 151

beneath the piston 158 during the active stroke when the tank 12 is being charged. On the return stroke for the follower piston 158, water flows through the ports 172 in the piston and around the flapper member 160 which is forced away from the piston to the position 160′ shown in dotted lines. In addition, water flows around the follower piston 158. Thus, following the return stroke, water is again disposed into the pump housing 151 between the follower elements 158—160 and the pump exit ports 153 to discharge into the tank 12 during the next actuation of the valve 123.

A three-way slide valve 116 is employed to operate a stop valve 106 for selectively expelling water from the tank 12. The valve 106 includes a valve housing 137 and pressure sensitive diaphragm 108. The stop valve housing 137 includes ports 110 through which water may selectively enter from the tank 12, and a discharge passageway 115 leading to the underwater medium. A conduit 104 is normally connected by the valve 116 to the relatively high pressure output of the regulator valve 15 to bias the diaphragm 108 downward over the ports 110 (position 108′ shown in dotted lines) hence preventing water from flowing from the tank 12 into the interior of the valve 106. When the valve 116 is operated, the conduit 104 is vented to the ambient medium and the diaphragm 108 is raised to the position 108″ (shown in chain lines) by the internal pressure of the tank 12, whereupon water flows from the tank through the ports 110 and is discharged through the passageway 115. Thus, water is continuously expelled from the tank 12 as long as the conduit 104 is vented.

The slide valve 116 includes an operating button 118 which is biased to an external rest position by a spring 120. The valve includes a slide member 124 with an aperture 126 thereon. When the button 118 is not activated, the aperture 126 connects the conduits 180 and 104 thus forcing the stop valve diaphragm 108 downward and sealing the valve ports 110. When the button 118 is depressed, the aperture 126 connects the conduit 104 with a valve venting port 130 thereby opening the water discharge path 110—115 as considered hereinabove.

To maintain the interior of the tank within a fixed pressure range above the ambient medium (e.g. 3—5 p.s.i. as discussed above), a three-way valve 86 includes a slide member 90 which is selectively operated by a differential pressure responsive regulating valve 80. The valve 80 includes a diaphragm 82 having one side exposed to the underwater medium, and the other side connected to the interior of the tank 12 by a port 81. The pressure of the underwater medium is increased by a spring 83 which adds an additional pressure in the range 3—5 p.s.i.

When the interior tank 12 pressure beneath the diaphragm 82 is approximately equal to the pressure on top of the diaphragm 82 (at a level given by the underwater ambient pressure plus the spring pressure), a connecting rod 84 connected to the diaphragm positions the slide member 90 in the three-way valve 86 to a neutral position. In this neutral position a valve 86 output conduit 96 is connected to neither the output of the regulator valve 15 via the conduit 182, nor to the ambient medium via a conduit 92.

Should the interior tank pressure become less than the desired pressure, the diaphragm 82 is forced downward by the spring 83 and the underwater medium. This, in turn, forces the valve 86 slide member 90 downward such that an aperture 93 in the slide member 90 connects the output conduit 96 with the pressurised conduit 182. When this condition obtains, air flows through the conduit 96, through a valve 98 and into the tank via two tubes 111 and 112. After sufficient air is inserted in the tank, the pressure coupled to the bottom of the diaphragm 82 via the valve port 81 returns the diaphragm 82 to its normal position thereby resetting the slide member 90 to its neutral rest position hence disconnecting the conduit 96 from the pressurised conduit 182.

If the interior pressure of the tank increases above the desired pressure (e.g. when the diver is rising such that the ambient pressure decreases, or when the pump 50 is actuated decreasing the residual air volume thus increasing its pressure) the port 81 couples a net positive pressure to the bottom of the diaphragm 82 thereby raising this member, along with the connecting rod 84 and the valve slide member 90. The slide aperture 93 then connects the conduit 96 with the venting conduit 92 such that air flows out of the tank via one of the conduits 111 or 112 (depending upon the orientation of the tank) and through the valve 98. Air is continuously vented until the pressures on both sides of the diaphragm 82 are equalised to maintain the slide member 90 in its neutral position.

The orientation sensitive three-way valve 98 and the two conduits 111 and 112 having their ends located in opposite portions of the tank 12 are employed to connect the conduit 96 with the vertically raised part of the tank which has air in it, and not to the lower tank portion which contains water. This selection permits the pressure in the tank 12 to be maintained within the desired range by removing air and not water when the internal tank pressure is to be reduced.

The valve 98 includes a housing 100 having end chambers 101 and 117, and a central chamber 113 connected to conduit 96. The

chamber 101 comprises the space between the end of the housing 100 and an annular ring 105, while the chamber 117 is disposed between the other end of the housing 100 and an annular ring 114. Two balls 102 and 103 are respectively disposed in the compartments 101 and 117 and selectively seal central apertures 107 and 109 in the annular rings 105 and 114, respectively, depending upon the orientation of the valve 98 as discussed below. The tube 111 connects the valve 98 compartment 101 to the bottom portion of the tank 12, and the tubing 112 connects the upper portion of the tank 12 to the valve compartment 117.

When the tank 12 resides in the vertical orientation shown, the ball 102 rests on the annular member 105 sealing the aperture 107 in this annular member. Accordingly, the ball 102 disconnects the conduit 111, having its free end disposed in the water-containing lower portion of the tank 12, from the conduit 96. Correspondingly, the ball 103 rests on the bottom of the housing 100, and the conduits 96 and 112 are thereby connected via the valve compartments 117 and 101 and the unblocked centre 109 of the annular member 114. Since water resides on the bottom of the tank when it is in the position shown, the conduit 96 is connected by the valve 98 and the tube 112 with the air containing upper portion of the tank 12.

When the tank is rotated to reverse the vertical orientation of the drawing (e.g. a diver descending head first), the ball 103 will rest on the ring 114 and seal the aperture 109. This isolates the conduit 96 from the tube 112 having its end now disposed in the water in the tank. Correspondingly, the ball 102 resides against the valve housing 100, and the conduits 96 is thus connected to the conduit 111 which terminates in the air containing portion of the tank.

The balls 102 and 103 are physically proportioned along with their seats 105 and 114, apertures 107 and 109, and the centre chamber 113, so that they cannot both be in a seated position at the same time because of interference.

Thus, the valves 80, 86 and 98, having the several conduits associated therewith, operate to maintain the interior of the tank within the desired pressure range of 3—5 p.s.i. above ambient pressure by selectively increasing or decreasing the air pressure within the tank 13 irrespective of the orientation of the tank.

Finally the tank contains a relief valve 176 which is adapted to open as a safety measure should the pressure within the tank exceed a predetermined limit for any reason (e.g. 10 p.s.i. above the ambient pressure).

With the above arrangement in mind, an illustrative sequence of operation for the buoyancy contolling apparatus will now be described. A diver just beginning his journey starts with his tank 12 substantially free of water and with an internal pressure between 3—5 p.s.i. above ambient pressure, as produced by the output of the regulator valve 15 acting through the conduit 182 and the valves 80, 86 and 98. The user swims on the water surface to the diving area with the empty tank serving as a flotation aid and not an encumbering weight which has to be transported.

At the diving location, the diver repeatedly actuates the button 121 to change his status from positive to neutral or slightly negative buoyancy. With each depression of the button 121, the pump 150 responds in the above-described manner to air pressure from the regulator valve 15 which drives the piston 154 via the valve 123 by forcing a fixed quantity of water through the tank ports 153 and into the tank 12. Since the tank 12 is of a fixed volume it displaces a like fixed volume of water when submerged. Thus, when water is introduced into the tank by the pump 150, the weight of this water directly subtracts from the fixed buoyancy force acting on the user and his submerged equipment, which again is of a fixed volume.

At neutral or slightly negative buoyancy, the diver is free to move about underwater as he desires without expending energy to maintain his underwater depth. As the buoyancy of the diver and his equipment decreases, e.g. because of increased water pressure as he moves to greater depths, he may compensate by releasing some of the water pumped in at the surface to begin his dive. Correspondingly, as his buoyancy increases because the user expends his air supply or moves to shallower water with less pressure and less "suit squeeze", the user simply pushes the button 121 to inject more water into the tank 12.

For any orientation of the diver and the tank 12, the valve 98 connects the conduit 111 or 112 terminating in the air containing portion of the tank 12 to the conduit 96. The diaphragm 82 and spring 83 normally position the valve 86 slide member 90 to a neutral position, and move the slide member to connect the conduit 96 via the conduit 92 or 182 to reduce or increase the tank pressure, respectively, if it departs from the desired value. Accordingly, the valve arrangement 80, 86 and 98 maintains the interior of the tank within the desired pressure range for any water depth and corresponding ambient pressure, and for any orientation of the diver. Since the internal tank pressure is maintained at a few p.s.i. above ambient pressure, the tank is not crushed at great water depths, even when fabricated of materials which are not normally form re-

taining or which do not possess sufficient inherent mechanical strength to withstand the ambient underwater pressures which may be extremely large.

When the diver wishes to increase his buoyancy, either as an assistance in rising or to correct for an overweighted condition, he depresses the button 118 to operate the stop valve 106. The internal pressure of the tank forces water in the tank 12 through the valve apertures 110 and out the passageway 115 into the underwater medium while maintaining the diaphragm 108 in a position away from the apertures 110. Water continuously flows out of the tank until the button 118 is released to again apply pressure from the conduit 180 to the conduit 104 to force the diaphragm 108 downward to seal the ports 110. As water is expelled, the downward weight force acting against the buoyancy force is continuously decreased thereby increasing net buoyancy.

If at any time the interior of the tank becomes over-pressurised, the relief valve 176 opens to vent the excessive air pressure.

Thus, the variable buoyancy arrangement depicted in Figure 2 and disclosed in detail above is readily operable under control of the user to generate any desired buoyancy condition for the user and his equipment vis.-a-vis. the surrounding underwater environment.

The arrangements described above are only illustrative of the principles of the present invention. Numerous modifications and adaptations thereof will be readily apparent to those skilled in the art without departing from the scope of the present invention. For example, the variable buoyancy apparatus may be used to help a diver carry heavy objects picked up on the bottom, or it may be attached to heavy objects to be transported for maintaining their buoyancy regardless of changing depths without the instability inherent in buoyancy tanks open to the sea.

WHAT WE CLAIM IS:—

1. In combination in a variable buoyancy arrangement adapted for underwater activity, a tank of substantially fixed volume for selectively storing water, means for maintaining the interior of said tank within a predetermined pressure range above the underwater ambient pressure, means for selectively introducing water into said tank, and means for selectively discharging water from said tank.

2. A combination as claimed in claim 1 wherein said selective water introducing means comprises a pump having a discharge port connected to said tank, a source of air at a pressure greater than the maximum pressure within said tank, and valve means for selectively energising said pump to cause introduction of water into said tank.

3. A combination as claimed in claim 2 wherein said pump comprises a pump housing, piston means movable within said housing, means for biasing said piston means, and means for connecting one side of said piston means to said air source, the other side of said piston means communicating with said pump discharge port.

4. A combination as claimed in claim 3 further comprising a check valve connected between said pump and said tank.

5. A combination as claimed in any of claims 2 to 4, wherein said tank pressure maintaining means includes pressure regulating means connected to the compressed air source providing a pressure of a predetermined value greater than the underwater ambient pressure and pressure reducing means connecting said pressure regulating means with said tank, and means for connecting said pressure regulating means to said pump.

6. A combination as claimed in any of claims 2 to 5, further comprising pressure relief valve means connected to said tank.

7. A combination as claimed in any of claims 2 to 6, wherein said selective discharge means comprises a stop cock connected to said tank.

8. A combination as claimed in claim 2 wherein said pump comprises a pump housing, a diaphragm attached to said housing, means for biasing said diaphragm, and means for connecting one side of said diaphragm to said air source, the other side of said diaphragm communicating with said pump discharge port.

9. A combination as claimed in claim 2 having a connection between said valve means and said air source for energising said pump as said valve means is operated.

10. A combination as claimed in claim 2 wherein said pump includes a cylinder, a discharge port connected to said tank, a drive piston having first and second surfaces, said drive piston being mounted for sliding translation within said cylinder, a pump chamber, a follower piston connected to said drive piston and located in said pump chamber, and means for selectively impressing a pressure gradient in said pump cylinder about said first and second driving piston surfaces.

11. A combination as claimed in claim 10 further comprising check valve means connected to said pump discharge port.

12. A combination as claimed in claim 11 wherein said check valve means includes flexible flapper sealing means located over said pump discharge port.

13. A combination as claimed in claim 12 further comprising check valve means included on said follower piston.

14. A combination as claimed in claim 13 wherein said follower piston check valve means includes apertures in said follower piston, and a flexible flapper sealing means disposed over said apertures.

15. A combination as claimed in any of claims 10—14 wherein said pressure gradient impressing means includes first and second conduits connected to said pump cylinder on opposite sides of said drive piston, a valve including an input port to be energised with pressurised air, at least one venting port, and means for alternately connecting one of said conduits connected to said pump cylinder to said pressurised valve port and for connecting the other of said conduits to said venting port.

16. A combination as claimed in any of claims 1 to 15 wherein said tank interior pressure maintaining means includes input means adapted for connection to a source of comprssed air, venting means, first valve means for selectively connecting said tank to one of said air supplying input means or to said venting means, and differential pressure valve means responsive to the pressure differential between the interior and exterior of said tank mans for selectively operating said first valve means.

17. A combination as claimed in claim 16 further comprising orientation-responsive valve means for connecting said first valve means to the upper portion of said tank.

18. A combination as claimed in claim 16 or 17 wherein said first valve means includes a slide member for selectively connecting said tank to said air input means, and wherein said differential pressure valve means includes a diaphragm having two surfaces respectively exposed to the environment outside said tank and to the interior of said tank, and means connecting said diaphragm with said slide member of said first valve means.

19. A combination as claimed in claim 18 further comprising spring means for biasing said diaphragm.

20. A combination as claimed in any of claims 1 to 19 wherein said water discharging means including stop valve means comprising at least one input port and at least one exit port, a diaphragm for selectively sealing said input port, and additional valve means for selectively operating said diaphragm.

21. A combination as claimed in claim 20 wherein said additional valve means includes a vent port, an air input port, a transferred port connected to said stop valve means, and slide means for selectively connecting said transferred port to said vent port or to said air input port.

22. A combination as claimed in claim 17 wherein said orientation responsive valve means includes three aligned compartments separated by two annular members each having a central orifice therein, ball means in the two end compartments for selectively sealing the central aperture in at most one of said annular members depending upon the orientation of said valve means, first conduit means connecting the central valve compartment with said first valve means, and additional conduit means connecting the end valve compartments with differing portions of said tank such that the portion of said tank oriented vertically upward is operatively connected by said additional conduit means and said orientation responsive valve means to said first conduit means.

23. A variable buoyancy arrangement constructed and arranged substantially as herein described with reference to Figure 1 or Figure 2 of the accompanying drawings.

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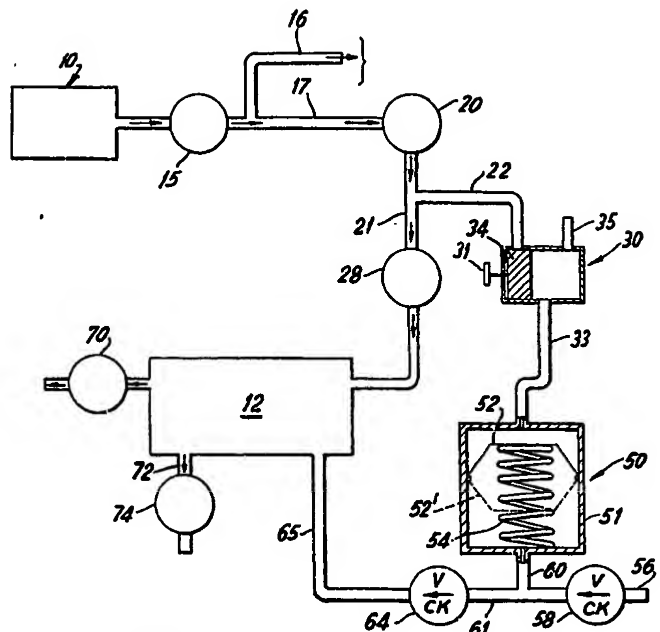
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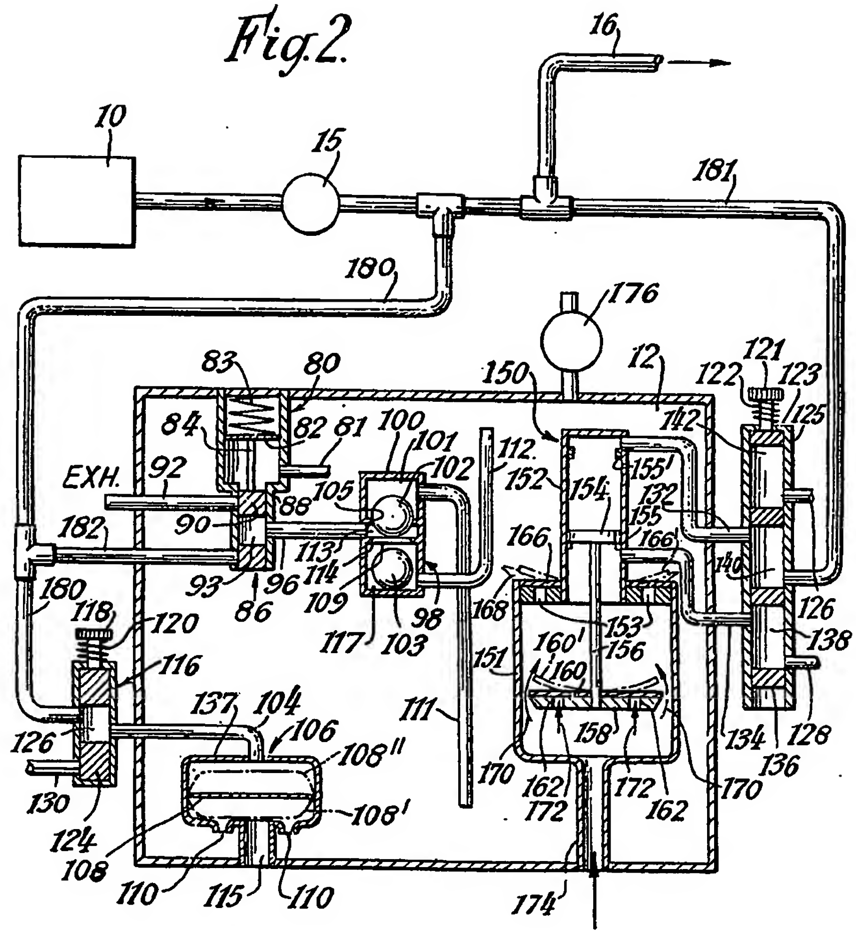
FIG. 1

Fig. 2.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